CAEP Memo 102, Attachment A, (4th July 2016):

• A scientific overview of aviation environmental effects related to the aircraft and engine at source;

• For each technology, assess the possibility of noise reduction and fuel efficiency improvement, with specific focus on the interdependencies and trade-offs between fuel efficiency and noise;

• An assessment of the technological possibilities for NO$_x$ and non-volatile Particulate Matter (nvPM) emissions control with specific focus on the interdependencies and trade-offs between fuel efficiency and/or noise.
The Independent Expert Integrated Review (IEIR) Panel

- Co-chairs:
  Nick Cumpsty (UK) and Dimitri Mavris (USA)

- 15 Independent Experts drawn from 7 nationalities:
  
  Fernando Martini Catalano (Brazil)  
  David Zingg (Canada)  
  Chris Eyers (EC)  
  Marius Goutines (France)  
  Alain Joselzon (France)  
  Juan Alonso (ICSA)  
  Iurii Khaletskii (RF)  
  Tomas Gronstedt (Sweden)  
  Frank Ogilvie (UK)  
  Malcolm Ralph (UK)  
  Jim Hileman (USA)  
  Jayant Sabnis (USA)  
  Rich Wahls (USA)
## Technology Reference Aircraft

Four types of aircraft considered each with notional reference aircraft selected

<table>
<thead>
<tr>
<th>Aircraft Class</th>
<th>Number of Seats</th>
<th>Notional Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Jet (BJ)</td>
<td>&lt; 20</td>
<td>Gulfstream G650ER</td>
</tr>
<tr>
<td>Regional Jet (RJ)</td>
<td>20 – 100</td>
<td>Embraer E190-E2</td>
</tr>
<tr>
<td>Single Aisle (SA)</td>
<td>101 – 210</td>
<td>Airbus A320neo</td>
</tr>
<tr>
<td>Twin Aisle (TA)</td>
<td>211 – 300</td>
<td>Airbus A350-900</td>
</tr>
</tbody>
</table>
Process to Assess the Technology Goals for each Technology Reference Aircraft

**STEP I:** 2017 Reference TRA

**STEP II:** 2017 TRA optimized

- **Technologies:** Fixed at 2017 TRA levels
- **Design Parameters:** Vary over parameter ranges

**STEP III:** 2027 & 2037 Setting Metrics, Interdependencies & Goals

- **Technologies:** Vary at three confidence levels (High, Nominal, Low)
- **Design Parameters:** Vary over parameter ranges
Implementing Future Technologies

• To protect proprietary data, **technology improvements** were received from ICCAIA for each timeframe (2027 and 2037) in following high-level areas
  – Aerodynamics: drag
  – Noise: airframe & engine noise sources
  – Structures: fuselage, wing and empennage weights
  – Propulsion: cycle, efficiencies, nacelle drag & weight, component weights

• Technology improvements given were applied to 2017 TRA at three confidence levels:
  – Low
  – Nominal
  – High

• Extensive interactions with industry and IEs
Single-Aisle TRA and Optimization

• Notional Airbus A320neo – Technology Reference Aircraft model
  – Assumed design payload 165 pax (15 Business & 150 Economy)
  – Design range of 3,500 nm
  – Two geared fan engines

• Optimized Vehicles
  – Varying design parameters to minimize fuel burn, noise, and NOx separately
  – Technology benefits held at three fixed levels agreed with ICCAIA, plus 7% increase in L/D
  – Subject to mission, wing span, and ground clearance constraints

• All vehicles are resized for all combination of design parameters and technology benefits.
• No NO\textsubscript{x} combustion technology improvements in modeling
• Current goals compared with earlier IE goals expressed as annual change in Fuel-Burn per available tonne kilometer Metric (FB/ATK) relative to the respective baselines for each review measured at the R1 point in the payload-range diagram.

• Current IEIR technology assessments reveal that the prior goals were more optimistic than the 2010 review.
Proposed Noise Goals

• Noise Goals Expressed as Cumulative EPNdB below Chapter 14 Noise Limit
• In comparison to the prior review, the percent improvement in noise margin is less in the long term due to the expectations of the technologies to bear in the future
Visualizing and Interdependencies using Pareto Frontiers

Optimization Clouds

Remove designs which violate constraints

Pareto Fronts

Cumulative Noise (EPNdB)

FB/ATK metric (kg/t-km)

Pareto front of constraint violating solutions (grey dots)

Pareto front of feasible solutions (black dots)

Cumulative Noise (EPNdB)

FB/ATK metric (kg/t-km)

TRA

100%FB / 0%Noise

0%FB / 100%Noise

2017

2017

100%FB / 0%Noise

0%FB / 100%Noise

Pareto Fronts

Remove designs which violate constraints

Cumulative Noise (EPNdB)

FB/ATK metric (kg/t-km)
Single Aisle Noise vs Fuel Burn Interdependencies

[Diagram showing the interdependencies between cumulative noise (EPNdB) and fuel burn (kg/ATK) for different years and scenarios. The bright green points indicate the 50/50 optimization points.]
Single Aisle Interdependencies relative to the 50% Fuel-burn/50% noise optimization point

<table>
<thead>
<tr>
<th>Year</th>
<th>Optimization weighting</th>
<th>Δ FB/ATK</th>
<th>Δ EPNdB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>100% FB</td>
<td>-0.2%</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>50/50</td>
<td>0.0%</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>100% Noise</td>
<td>0.8%</td>
<td>-0.7</td>
</tr>
<tr>
<td>2027</td>
<td>100% FB</td>
<td>-0.5%</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>50/50</td>
<td>0.0%</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>100% Noise</td>
<td>2.9%</td>
<td>-1.1</td>
</tr>
<tr>
<td>2037</td>
<td>100% FB</td>
<td>-1.2%</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>50/50</td>
<td>0.0%</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>100% Noise</td>
<td>3.4%</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Model Optimization for Nominal Confidence. Performed at $R_1$ of 2017 TRA. Change in FB/ATK reported at the design range.
Concluding Remarks

- IEIR process led to an accepted set of mid- and long-terms goals for fuel burn (CO₂), noise, and while accounting for NOₓ interdependencies.

- Consideration was provided on:
  - Aviation’s environmental, climate, and health impacts
  - Advanced configurations
  - Alternative approaches

- IEs recognized that the current goals were less aggressive than prior reviews predominantly because the baseline vehicles were more current.

- IEs concur with ICCAIA’s view that further environmental improvements can be achieved through the infusion of new advanced configurations.